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G. W. Morgan
Office of Radiation Standards

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Basic Concepts in the Safe Use of Radioactive Materials

By G. W. MORGAN*

BIOLOGICAL EFFECTS OF IONIZING RADIATION

Mankind has always been exposed to ionizing radiation from cosmic rays and naturally occurring radioactive materials in the environment and within the body. In addition to this exposure from "natural background radiation" man may receive additional exposure from radiation producing machines and man-made radioactive materials. Ionizing radiation—which includes x-rays; gamma rays; alpha, beta, neutron and cosmic radiation—imparts energy to matter through which it passes. For x-rays and gamma-rays, the unit of measurement of radiation is the roentgen (r) which may be considered in terms of the absorption of energy. Since absorption by human tissue of the same amounts of energy from different types of radiation does not result in the same biological effect, radiation doses are commonly expressed in terms of the "rem" or "Roentgen Equivalent Man." One "rem" of any ionizing radiation produces the same biological effect as one roentgen of x-rays.

The extent to which a given biological effect is manifested depends upon the total amount of radiation absorbed, the rate at which this radiation is absorbed, the area of the body exposed, the relative sensitivity of the cells and tissues receiving the exposure and other factors. Radiation exposures are classed as "acute" (of short duration) or "chronic" (of a continuous or fractionated nature and extending over a long period of time). Acute exposures can result in both immediate and delayed biological effects while chronic exposures are usually considered to produce only delayed effects.

Available data on immediate effects of radiation on humans are derived primarily from medical findings following therapeutic

* Chief, State-AEC Relations Branch, Office of Radiation Standards.

exposures, accidental exposures of radiologists or workers in the nuclear industry, and population observations on atomic bomb survivors and persons irradiated by heavy fallout in the vicinity of the Marshall Islands. Most delayed effects in man are inferred from animal studies, available epidemiological observations, and a limited number of medical and industrial case observations. "The effects considered are: (1) genetic effects; and (2) somatic effects, including the appearance of leukemia, skin changes, precancerous lesions, neoplasms, cataracts, changes in life span, and effects on growth and development. The delayed effects produced by ionizing radiation in an individual are not unique to radiation and are for the most part indistinguishable from those pathological conditions normally present in the population and which may be induced by other causes."[1]

The probable early biological effects of acute whole body exposure to radiation from sources outside the body are summarized in Table I.

TABLE I
SUMMARY OF EFFECTS RESULTING FROM ACUTE WHOLE BODY EXTERNAL EXPOSURE OF RADIATION TO MAN[2]

0-25 r	25-100 r	100-200 r	200-300 r	300-600 r	600 or more
No detectable clinical effects. Delayed effects may occur.	Slight transient reductions in lymphocytes and neutrophils. Disabling sickness not common, exposed individuals should be able to proceed with usual duties. Delayed effects possible, but serious effects on average individual very improbable.	Nausea and fatigue, with possible vomiting above 125 r. Reduction in lymphocytes and neutrophils with delayed recovery. Delayed effects may shorten life expectancy in the order of one per cent.	Nausea and vomiting on first day. Latent period up to two weeks or perhaps longer. Following latent period symptoms appear but are not severe: loss of appetite, and general malaise, sore throat, pallor, petecheae, diarrhea, moderate emaciation. Recovery likely in about 3 months unless complicated by poor previous health, superimposed injuries or infections.	Nausea, vomiting and diarrhea in first few hours. Latent period with no definite symptoms, perhaps as long as one week. Epilation, loss of appetite, general malaise, and fever during second week, followed by hemorrhage, purpura, petecheae, inflammation of mouth and throat, diarrhea, and emaciation in the third week. Some deaths in 2 to 6 weeks. Possible eventual death to 50% of the exposed individuals for about 450 roentgens.	Nausea, vomitin and diarrhea in first few hours. Short latent peric with no definite symptoms in son cases during firs week. Diarrhea, hemorrhage, purpura, inflammation of mouth and throa fever toward enc of first week. Rapid emaciatio and death as ear as the second we with possible eventual death up to 100% of e posed individual

[1] Fed. Radiation Council, *Background Material for the Development of Radiation Protection Standards,* Report No. 1 (May 13, 1960).

[2] Fed. Radiation Council, *Background Material for the Development of Radiation Protection Standards,* Report No. 1 (May 13, 1960), as adapted from U.S. Gov't Printing Office, The Effects of Nuclear Weapons (1957).

Delayed biological effects may result from either acute or chronic exposures to radiation. In the use of radioactive materials, the delayed effects resulting from small doses of radiation delivered continuously or in small increments and over an extended period of time are of greatest importance.

MAXIMUM PERMISSIBLE RADIATION DOSE

For the past 30 years, the National Committee on Radiation Protection and Measurements (NCRP) has been studying the entire area of permissible radiation exposure and during that time has made recommendations on the permissible radiation dose. Permissible dose may be defined as the dose of ionizing radiation that, in the light of present knowledge, is not expected to cause appreciable bodily injury to a person at any time during his lifetime.[3] It has been the policy of the Atomic Energy Commission to follow recommendations of the NCRP. Since the establishment of the Federal Radiation Council in 1959, the AEC follows the recommendations of the Council, as approved by the President. The basic radiation exposure standards in AEC's "Standards for Protection Against Radiation"[4] represent the legal adaptation of these recommendations. In general, a person who is occupationally exposed to radiation may receive a whole body dose not exceeding 1.25 rem in any calendar quarter or 5 rem in any year. In cases where the past exposure of an individual is documented and is sufficiently low, exposures of up to 3 rem in any one quarter or 12 rem in any year may be permitted. Less restrictive permissible doses have been established for occupational exposure of certain limited portions of the body. Permissible dose limits for individuals not occupationally exposed to radiation are in general one-tenth the occupational limits.

RADIATION PROTECTION

The principle types of radiation emitted by radioactive materials are (1) alpha particles, (2) beta particles, and (3) gamma rays. Alpha particles have the least penetrating power. Their

[3] National Committee on Radiation Protection, Protection Permissible Dose from External Sources of Ionizing Radiation, Handbook 59 (Sept. 1954).
[4] 10 C.F.R. §§ 20.1-601 (Supp. 1961).

range in air is only a few inches, while they are completely absorbed by a sheet of paper. Beta particles are more penetrating, having a range up to several yards in air, but they are absorbed by a fraction of an inch of glass or plastic. On the other hand, gamma radiation is very penetrating, and several inches of dense material such as lead or concrete shielding may be needed to afford protection for general use of gamma emitting radioisotopes. Thus, in work with radioactive materials radiation presents protective problems which differ with the type and amount of radiation involved, the form of the material and the operation to be performed. From the standpoint of health protection, the problems are both external and internal. These exposure problems are controlled largely through safe design engineering of equipment and facilities and the use of proper handling and control techniques.

In addition to these general problems, special problems are encountered in the disposal of radioactive wastes, the protection of instruments during sensitive measurements, and the prevention of contamination of the laboratory, analytical samples and products.

PROTECTION FROM EXTERNAL EXPOSURE

Protection from external exposure is afforded by (1) maintaining distance between the user and the radiation source, (2) employing shielding, and (3) limiting the time of exposure. The effectiveness of any one or any combination of these factors is dependent upon the type and energy of the radiation and the level of activity. For very low levels, sufficient protection may be afforded by limiting exposure time. For higher levels, it may be necessary to limit exposure time and employ remote handling equipment. Still higher levels of activity may require the use of shielding.

PROTECTION FROM INTERNAL EXPOSURE

Protection from internal exposure is afforded by preventing the entrance of radioactive material into the body through ingestion, inhalation or incisions. In laboratory work the principal source of ingested contamination is through secondary transfer from contaminated hands or objects. Surfaces are contaminated by direct contact, by contact with handling equipment, by the settling of contaminants from the air, or by absorption of radioactive gases from the air. Air may be contaminated by radioactive gases, dusts, mists, fumes, or vapors, or from suspension of contaminants from surfaces. Incisions become contaminated by direct transfer from contaminated objects making the incision, or by transfer of contaminants from body surfaces or clothing into the incision.

The hazard produced by radioactive materials entering the body depends upon the radiotoxicity of the substance in question and the quantity of activity. The radiotoxicity depends upon such factors as (1) half-life,[5] (2) energy and character of radiation, (3) degree of selective localization in the body, (4) rates of elimination, and (5) quantities involved.

Radioactive material entering the body is metabolized and absorbed by the body tissue and organs in accordance with the chemical and physical characteristics of the material as though it were not radioactive. Selective absorption and deposition for most materials result in higher concentrations in certain tissues and organs than in others. Thus, the concentrations of materials in a limited portion of the body may be the limiting factor on the maximum permissible body intake for a particular radioactive material. Once radioactive materials are deposited internally, they cause continuous exposure to the surrounding tissue. The rate of exposure, however, is reduced by the decay of the radioactive materials and by elimination through ordinary body processes. In some instances special measures may be taken to hasten the release of radioactive materials from the body.

In order to limit the amount of material taken into the body so that the exposure of body tissues will not exceed the maximum permissible values, maximum permissible concentrations have been set for the various radioisotopes in air and water. Where exposure of the general public may be involved, maximum permissible concentrations are further reduced to limit such exposure to one-tenth that of radiation workers.

The best way to cope with contamination is to prevent its occurrence by exercising a high degree of control over the radio-

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[5] The time required for the radioactivity to be reduced by one-half through radioactive decay.

active material. This is accomplished by using proper equipment and facilities and by practicing suitable techniques. Contamination of air in the laboratory is prevented or minimized by use of ventilating systems such as hoods or closed systems such as gloved boxes in which operations are performed without the escape of material. When ventilation or closed systems are inadequate, respiratory devices should be worn. In typical laboratory operations such protective devices are not required. Laboratory surface contamination is prevented by use of proper containers and techniques and by covering surfaces with trays, absorbent paper, etc. Clothing contamination is prevented by wearing laboratory smocks, gloves, and other protective garments depending upon the particular needs.

PROTECTION IN LABORATORIES

Laboratories designed for routine use of radioisotopes are similar, in most respects, to those used for other purposes. The principal consideration is the provision of sufficient space to permit segregation of the various laboratory procedures and effective use of the special facilities, to protect personnel from external and internal exposure and to prevent contamination of the laboratory, analytical samples and products.

In addition to the need for such things as shielding and storage facilities, the floors, walls, benches, sinks, etc., should be of materials which are not readily contaminated and which are easily decontaminated; also special tongs and other remote handling equipment are needed. For certain specialized operations and operations involving high levels of radioactivity, specialized facilities are necessary.

WASTE DISPOSAL

The parameters of the problems of radioactive wastes disposal are beyond the scope of this paper. Basically, wastes are controlled by confinement or dilution. Confinement is effected by storage of materials having short half-lives until the radioactivity is negligible, burial in the soil or selected locations in the ocean or encasment in concrete or other material. On the other hand, materials may be disposed of by dilution in air, water or other medium until the activity per unit volume is negligible.

For typical radioisotope operations, gaseous effluents are disposed of by dilution in the atmosphere and liquid effluents are disposed of by release to sanitary sewage systems. When disposal of liquids in the sanitary sewers is impractical, they may be concentrated, and stored or buried. Except for limited amounts, wastes should not be buried in the soil unless the topographical, geological, and hydrological characteristics of the area have been determined as adequate for this purpose. For very long half-life materials in substantial quantities, the burial ground may require surveillance in perpetuity.

SURVEYS AND MONITORING

Radiation surveys (measurements) to determine the rate of exposure are necessary in order to evaluate the adequacy of handling devices, shields and techniques used. In order to keep records on the exposure of individuals occupationally exposed to radiation, personnel monitoring devices such as film badges or pocket meters are worn. Film badges are normally worn for one or two weeks before being processed and read whereas pocket meters are read daily. In special instances equipment is needed for sampling and measuring the amount of radioactivity in the air.

REGULATIONS

The AEC discharges its regulatory responsibility through a system of licensing and inspection to enforce its regulations. The principal purpose of the licensing program is to enable the Commission to insure before an applicant receives radioactive materials that his training, experience and facilities are adequate to enable him to comply with the Commission's radiation safety regulations and other regulatory requirements. After the licensee procures his licensed radioactive material, inspections are made to determine whether he is complying with the Commission's orders and regulations, and any special terms and conditions which have been incorporated in the license.

The Commission's "Standards for Protection Against Radiation," specifies maximum permissible exposure values, lists maximum permissible concentrations of radioactive materials[6] in air and water and limits radiation levels in uncontrolled areas.

Procedures for such precautionary functions as radiation surveys, personnel monitoring, area posting, container labeling and personnel instruction are required. In addition, reporting and record-keeping requirements are specified and limitations are placed on waste disposal practices.

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[6] 10 C.F.R. §§ 20.1-601 (Supp. 1961).